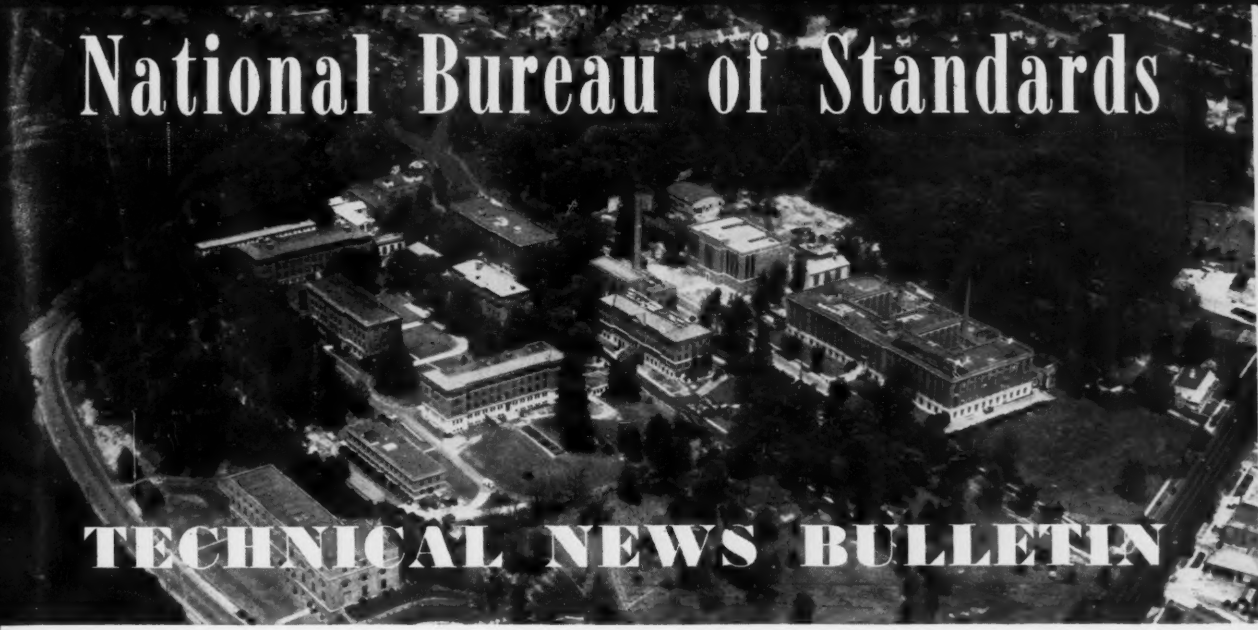

VOLUME 31 JULY 1947 NUMBER 7

Electronic Timer for Viscosity Measurements

A new electronic timer, particularly adapted for use with a falling-ball viscosimeter in the study of the rapidly changing viscosity of an opaque fluid, has been designed by P. J. Franklin of the National Bureau of Standards. The device consists of pulse-sharpening and trigger circuits, and the passage of the ball through two coils around the viscosimeter tube is used to trigger a radio-frequency oscillator, starting and stopping a timing device.

In measuring viscosity by the falling-ball method, a closed tube, surrounded by a constant-temperature jacket and containing a ball immersed in the liquid to be studied, is quickly inverted. Viscosity is determined from the rate of descent of the ball through the liquid, and this requires accurate timing, which the electronic timer provides. The method is very useful for viscosity measurements in many industries—for example, in the production of paints and lacquers where the instrument must be enclosed to prevent evaporation of volatile solvents. The falling-ball viscosimeter is also used in the oil and asphalt industries. Here the opacity of the liquids involved makes nonvisual timing a necessity. For similar reasons, viscosity measurements of catsups, jams, jellies, and other foods are perhaps most efficiently carried out with a falling-ball apparatus equipped for electronic timing.

A comparatively simple circuit was developed for the timer, making use of the radio-frequency induction field. The output of a 1,400-kilocycle crystal oscillator is link-coupled to the start- and stop-coils surrounding the viscosimeter tube. No buffer amplifier is required. A small padding condenser is placed across each coil, so that the amount of detuning is the same in both coils as a steel ball falls through them, changing the inductance of each coil in turn.

The radio-frequency power from each coil is rectified in the separate diodes of a 6SQ7 tube, and the resulting change in cathode current is amplified in the triode portion of the tube to obtain sufficient voltage variation to operate a pulse-sharpening circuit consisting of two 0.04-watt neon bulbs in series with a load resistor. When the voltage in the plate circuit of the amplifier rises to the ignition point of the neon tubes, the neons suddenly fire and a sharp pulse is produced across the load resistor. These tubes have a small amount of radium added to provide uniform ignition voltage regardless of illumination. Furthermore, they have the advantage that once ignited they stay ignited until the output voltage of the triodes has dropped to a low value, allowing only one pulse to occur with the passage of the ball through each coil. Both pulses are placed on the grids of a trigger pair, which on the first pulse closes a relay that starts a clock and on the second pulse opens the relay to stop the clock. Time of fall, as measured with this circuit for one direction of travel, was found to be reproducible within 0.01 second for a fall time of 2.5 seconds.

The electronic timer was designed for a process requiring repeated measurement of the viscosity of an

opaque liquid held within a limited-temperature range. Several standard methods of determining viscosity are used in the laboratory. Most of these may be grouped into those based upon rate of flow through a capillary tube or through a small orifice and those depending upon the rate of rotation of a cylinder or paddle wheel within a cup containing the liquid. Use of capillary tubes was considered impractical for measuring the viscosity of the opaque liquid, as the tubes would need continual refilling and would also be very difficult to clean after the material had set. If rate of flow through an orifice had been used, holes of increasing size would have been required as the liquid became more viscous. In the paddle wheel or cylinder methods, handling or cleaning would have been inconvenient after the material had thickened. Nor were any of these procedures well adapted to temperature control. It was therefore decided that the falling-ball apparatus was the most suitable for this application. The opacity of the material being studied, however, precluded the use of visual timing.

Although various electrical methods employing the conductive or magnetic characteristics of the falling ball had previously been used to measure its time of travel, none of these methods was considered completely satisfactory, due to lack of sensitivity, poor reproducibility of results, or the complicated nature of the circuit required. The induction method used in the timer proved to be the answer to the problem.

TECHNICAL NEWS BULLETIN

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W. Averell Harriman, *Secretary*
National Bureau of Standards
E. U. Condon, *Director*

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Contents

Timing of a falling-ball viscosimeter is accomplished automatically by means of a new electronic timer (right) developed at the bureau. The timer was especially designed for measurement of the rapidly changing viscosity of an opaque fluid. Passage of the ball through two coils sur rounding the viscosimeter tube affects the inductance of each coil in turn, operating an electronic circuit that starts and stops the timing device.

An Indentation Method for Measuring Wear

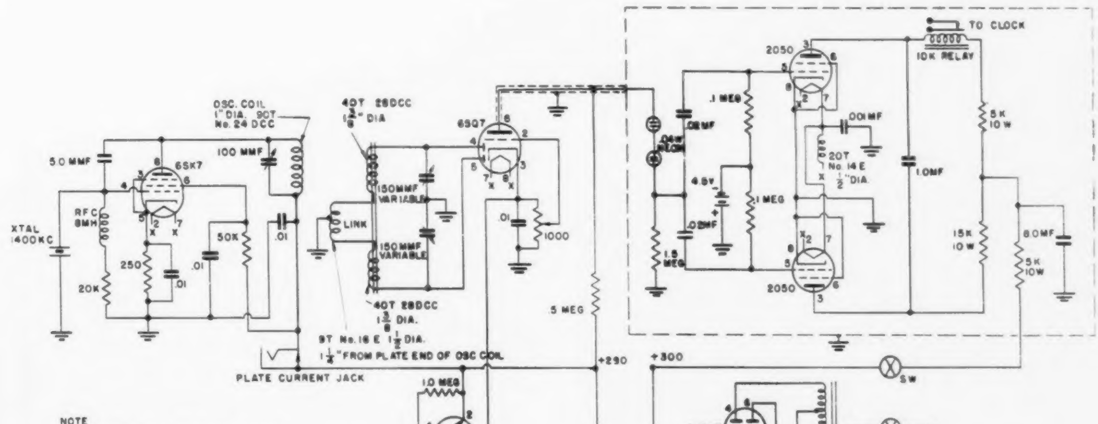
A major difficulty in measuring wear of machinery surfaces has been lack of a convenient method for accurately determining the amount of material worn off. Among methods that have been used are weighing and measuring dimensions of parts before and after wear, and determination of worn material in the lubricant after operation. Even under ideal conditions these methods have serious limitations. Such limitations, coupled with the fact that the methods often measure other conditions along with wear, indicated the desirability of a method for measuring wear that is independent of size or mass of the wearing piece.

Investigations conducted at the National Bureau of Standards under S. A. McKee led to the adaptation of a diamond indentation method of measuring wear. As a result a sensitive measuring instrument,[1] the McKee Wear Gage, was developed to measure extremely small increments of wear, as little as one hundred-thousandth of an inch under favorable conditions—considerably less than with other methods. By applying to the working surfaces narrow diamond-shaped markings that show a definite change in one or more readily measurable dimensions after relatively small amounts of wear, the gage provides a determinable indication of wear at the point where the marking is made.

Extensive tests at the Bureau have provided conclusive evidence that the indentation method of determining wear overcomes the shortcomings of other methods. For example, the weighing method gives a value for the total wear but does not indicate where the wear occurred. Measuring the changes in the dimensions of a worn piece has this same limitation to a lesser degree and does not differentiate between actual wear and other changes that may occur such as growth, shrinkage, or distortion of the part. The method of determining the amount of worn material in the lubricant presents a number of difficulties and usually is used only as a qualitative indication in conjunction with other data.

The McKee gage was designed primarily to locate and measure indentation marks on the cylinder walls and pistons of radial aircraft engines, as permanent distortion of such parts during operation had heretofore nullified the significance of any previous methods of measurement. The choice of the type of mark was influenced by an earlier development at the Bureau—the Knoop Indenter for measuring the hardness of materials.

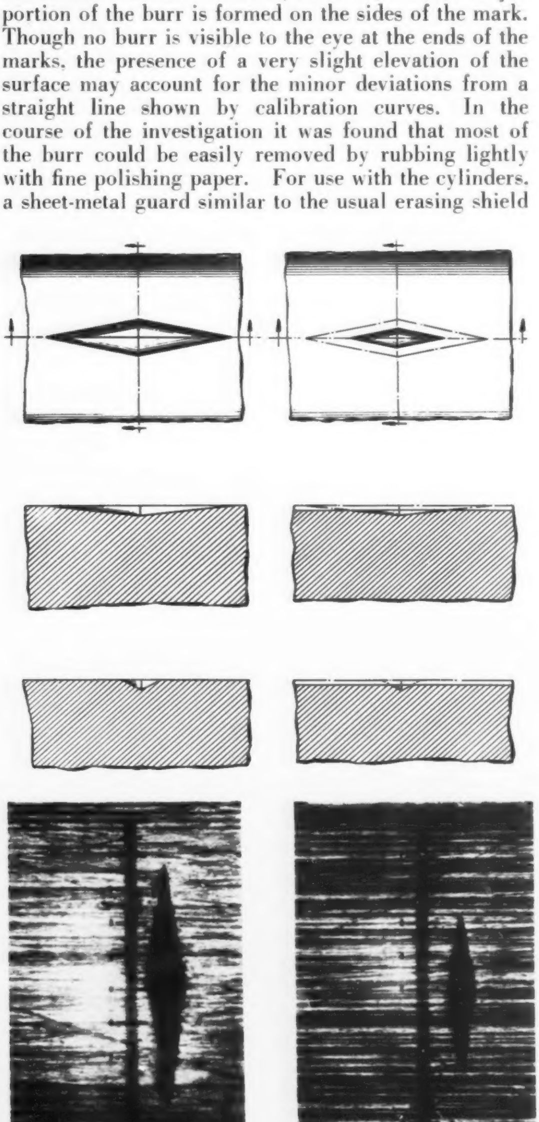
Special apparatus was developed for making and measuring the marks placed on the wearing surfaces by the diamond indenter of the wear gage. With a cylinder or piston mounted in a specially designed fixture, marks are applied at any desired position on the surface by means of the diamond point, which is forced by mechanical pressure to a predetermined depth into the surface piece. The viewing and measuring apparatus



The electronic timer for viscosity measurements consists of crystal oscillator, tuned diode detector, pulse-sharpening circuit, and trigger pair, operated on a common power supply. Output of the oscillator is fed into two coils surrounding the viscosimeter tube. The inductance of the coils is changed as a steel ball passes through the tube. The resultant change in power from each coil, on amplification, offers sufficient voltage variation to operate the pulse-sharpening circuit. The two short pulses, applied to the trigger pair, start and stop the clock.

consists of a conventional microscope and eye-piece scale, modified by the addition of two right-angle prisms so that it may be used as a periscope for viewing the inside of the cylinders.

The impression of the marks in the surface of the metal raises a burr around the mark. The shape of the diamond indenter is such, however, that the major portion of the burr is formed on the sides of the mark. Though no burr is visible to the eye at the ends of the marks, the presence of a very slight elevation of the surface may account for the minor deviations from a straight line shown by calibration curves. In the course of the investigation it was found that most of the burr could be easily removed by rubbing lightly with fine polishing paper. For use with the cylinders, a sheet-metal guard similar to the usual erasing shield



Extremely small increments of wear are measured by the wear gage. Enlarged diagrams illustrate the sections of a mark as applied (upper left) and after wear (upper right). Two marks after engine operation (lower) are about three-quarters and one-half their original length of 0.9 mm.

but of larger dimensions was found convenient. The holes in this guard are so arranged that the polishing paper can be rubbed over a small area at each mark on the cylinder wall with one finger.

As the marks are placed with their long axes perpendicular to the axis of the cylinder, the relation between the change in depth of mark to change in length of long axis is affected by the curvature of the cylinder. Although this effect is relatively small for the particular cylinders used, suitable corrections for curvature provide greater accuracy in determining wear.

A study was also made of the possibility of error due to the axis of the diamond indenter not being at right angles to the surface when the indentation is made. Computations indicated that if the diamond-shaped mark was symmetrical to within a ratio of not less than 41 to 50 along its major axis, the error would be no greater than 1 percent (approximately 0.00001 in.) It was found that the apparatus could be adjusted to produce a symmetrical mark and that other marks, either in the same cylinder or in other cylinders of the same nominal size, could be made well within the limits of symmetry without further adjustment.

Engine Tests

One of the important considerations in the Bureau's investigation was uncertainty as to whether the marks would return to their shape during operation of the engine. Results of a number of engine tests have shown that marks in the cylinders of radial aircraft engines retain their shape sufficiently to provide reasonably accurate wear measurements. Experience has indicated that results are not as satisfactory after the marks have been worn to about one-fourth of their original length or less. Hence greater accuracy may be obtained by carefully regulating the size of the mark and adjusting the duration of the test to prevent this condition.

The precision of the wear measurements depends upon the condition of the indentation. With new marks the points are sharp, and the lengths can be accurately determined. However, after the engine has been operated the marks are somewhat blunted, and it is necessary to estimate the position of the point. Under normal conditions the cylinder wear can be determined with an over-all accuracy of ± 0.00004 inch. For more favorable conditions the degree of accuracy can be increased to ± 0.00002 inch. Operating experience with marks in the pistons indicates that, with the softer aluminum alloy, the marks have a much greater tendency to distort, and the results are not entirely satisfactory. Another difficulty with this material is its tendency to become impregnated with carbon, making it difficult to distinguish the marks.

Most of the engine tests for determining the performance of the marks in service were made with Pratt and Whitney R-1535 engines having chrome-molybdenum steel cylinder barrels $5\frac{3}{16}$ inches in diameter. In these tests 24 marks were made in each cylinder, 6 spaced 60 degrees apart at each of 4 levels—approximately 2, 4, 6, and 8 inches from the open skirt end of

the cylinder. The upper row of marks was in contact with the top ring only while the lower was contacted by the oil ring. Typical cylinder wear patterns obtained in these tests reveal unsymmetrical wear with respect to the axis of the cylinder that would be impossible to determine with usual measurements of diameter.

Employing the basic principles of the original McKee gage, an instrument was designed by the American Instrument Co. for use with automobile engines in which the cylinders are cast into a single engine block. This instrument, used in an extensive series of tests by C. S. Bruce, J. T. Duck, and A. R. Pierce of the Bureau's Automotive Section, permitted accurate studies of the effects of wear in stock passenger-car engines operated under controlled conditions. The test engines were operated for 144 hours (approximately 3,000 miles of normal operation) between wear measurements, the operating cycle consisting of 20 minutes of actual operation with a 10-minute stop for cooling. During the stop period a special cooling system reduced the temperature so that the engine was started from a cold condition at the beginning of each ½-hour period.

Results of these tests, in which the average cylinder wear was about 0.00002 inch per 1,000 miles of operation, verify a previously accepted theory that operating conditions have a decided effect on cylinder wear, there being in general a greater amount of wear when starting the engine at low temperature than at high temperature (50° C). The data provided by such sensitive determinations of wear also indicated the possibility that corrosion is responsible for a major part of the wear occurring in normal operation of an engine. It is believed that moisture condensing on cold cylinder walls serves as a base for the formation of corrosive acids from the gases in the products of combustion. It appears that engine life may be substantially increased by any feature of design that accelerates the engine warmup or prevents the temperature of the cylinder walls from falling below the dewpoint of the exhaust gases. Additional data on the corrosive qualities of fuels would be desirable.

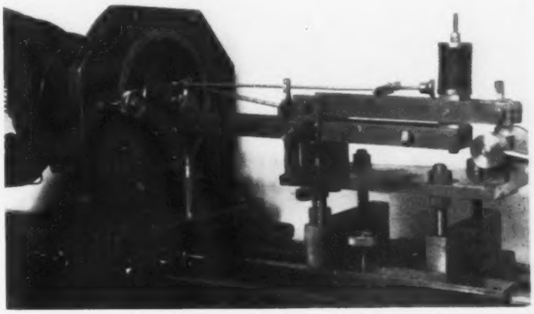
The indentations used in the studies at the Bureau were made by impressing into the test surface the apex of a four-sided diamond pyramid. From the standpoint of accuracy the chief limitation is that the sharp points of the marks are blunted somewhat when wear occurs. Possible use of cutting or grinding methods for producing marks without burrs and without sharp-pointed ends presents a promising field for further investigation. If this can be accomplished, the accuracy of determining wear would be greatly increased.

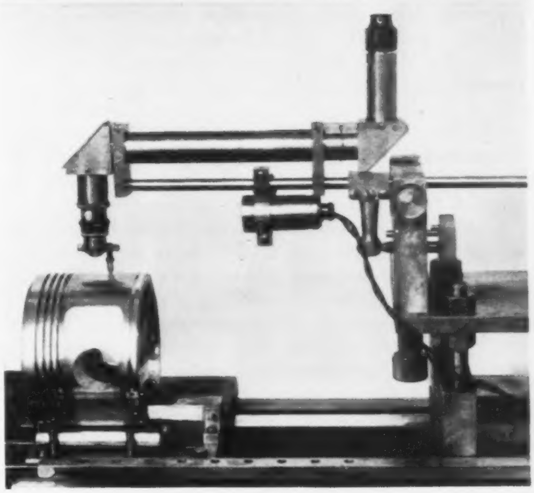
The McKee wear gage provides the particular advantage of an indication of wear only, while the usual measurements of changes in diameters of the pistons and cylinders do not differentiate between wear and distortion that may occur during a test. It also indicates wear at a particular point on the surface, whereas measurements of diameter involve changes at two points and practical means are not generally available for determing the amount of wear at each point. Also, the method does not require the careful technic necessary to measure diameters with corresponding accuracy.

As temperature variations do not materially affect the accuracy with the indentation method, it is not necessary to bring the cylinder to a definite temperature before making the measurements. The apparatus is provided with locating pins, and is so arranged that a mark made at given pin settings will fall within the field of vision of the periscope at the same settings.

In addition to its use as a practical method of measurement of wear in aircraft and automotive engine cylinders, the indentation principle appears applicable to other machine elements, gages, dies, and wearing surfaces where the material is of such a nature that the indented marks will retain their shape in service. For example, a mark placed on the wearing surface of certain production dies would readily indicate when they had been worn beyond specified tolerances.

[1] Developed at the National Bureau of Standards by S. A. McKee at the suggestion of, and with collaboration of, H. C. Dickinson. The method is covered by U. S. Patent No. 2,233,403, granted to Dickinson and McKee, and assigned by them to the United States Government.





The wear gage utilizes an indentation made by forcing a diamond point, under mechanical pressure, into a surface, e. g., an aircraft engine cylinder (upper), held in a special fixture. The periscope arrangement (lower) permits viewing both inside and outside surfaces.

NBS Casting Resin

During the war, exacting mechanical and electrical stability requirements of special electronic applications —such as the radio proximity fuze—necessitated potting of the circuit components. Due to the high impedance of the circuits involved, the electrical loss factor or the dissipation of the available energy in the casting or "potting" compound was of major importance. An extensive investigation of various available casting resins at the National Bureau of Standards revealed none suitable for the particular applications because of the high loss factor. The few materials with adequate electrical properties were mechanically deficient. In addition, the applications required a resin of such viscosity that the potting compound would encompass all the circuit elements when poured into a container housing the electronic device, and then harden to a rigid solid without adversely affecting circuit operation.

Many casting resins have been developed, but few have the vital electrical properties for proper operation of high-impedance, high-frequency equipment. As a result of experience gained in the fuze-development program at the Bureau, a new casting resin embodying the required mechanical and electrical properties was formulated by P. J. Franklin and M. Weinberg through a systematic variation of resin constituents. Various applications at the Bureau indicate that, with slight modifications to suit the intended use, the new potting compound—known as NBS Casting Resin—can be readily employed in many high-frequency devices requiring such mechanical-electrical insulation.

The most important properties specifically desired of a casting resin when utilized at high frequencies in high-impedance circuits are low power factor, low dielectric constant, short polymerization period at low temperature and atmospheric pressure, high impact strength, small volume shrinkage on polymerization, dimensional and electrical stability, and low moisture absorption. The NBS Casting Resin not only meets these requirements but fulfills the additional requirements of low viscosity and low surface tension, and hence may be poured through small openings.

Only nonpolar substances have a dielectric loss low enough to be considered applicable to high-frequency work. These substances, limited in number, have characteristics that restrict their use as casting resins. Isobutylene, ethylene, and tetrafluoroethylene are unsatisfactory because of their polymerization temperature and pressure requirements. N-vinyl carbazole polymerizes too slowly at permissible temperatures (requiring more than a week) and, being a solid, may not be poured. Styrene polymerizes in a few days and 2,5-dichlorostyrene in much less time, but the shrinkage on polymerization for both compounds is too great. By copolymerizing and by adding polymers as fillers to monomers, however, a number of suitable casting resins were produced. At present the best compound attained is the NBS Casting Resin.

The rate of polymerization of styrene is accelerated by the addition of dichlorostyrene and a solution containing 60 percent mixed isomers of divinylbenzene. The dichlorostyrene serves also to reduce flammability, as well as to permit the use of divinylbenzene as a cross-linking agent. This completely removes the "cauliflower" effect produced when divinylbenzene is polymerized with styrene at a low temperature. The polymers of styrene and 2,5-dichlorostyrene act as fillers to cut down the over-all shrinkage due to polymerization.

By producing cross-linkage in the final product, the divinylbenzene imparts to the polymer certain thermosetting characteristics that slightly increase the heat-distortion point. Preliminary tests of mixed isomers of dichlorostyrene indicate that they may be substituted for dichlorostyrene with only minor losses in dielectric characteristics and compatibility.

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The new NBS Casting Resin was formulated to provide sui[...] mecha[...] require potting. Laboratory preparation is relatively simple. Mixing [...] readily be poured (2) to embed the circuit completely. [...]ing in [...] important electrical properties, low power factor and dielectr[ic] constan[...] stage control unit (4) and a commercial dual-stage amplifie[r] printed [...] devices that have been embedded in NBS Casting Resin for pr[ote]ction ag[...]

Preparation and Polymerization Technic

Preparation of the casting resin is relatively simple. Immediately after putting the components in a suitable mixing vessel, the mixture is placed on a roll mill to prevent clumping and is rolled until a viscous dispersion is formed. Following about 16 hours of continuous rolling, the casting resin is ready for use, requiring only the proper quantity of catalyst to initiate polymerization. Special treatment must be given the 2,5-dichlorostyrene and styrene, as they may contain an excessive amount of inhibitor which, if not removed, would interfere with the polymerization and electrical properties of the casting resin. The inhibitor may be conveniently removed by treating the monomer with a 10 percent sodium-hydroxide solution, followed by washing and drying.

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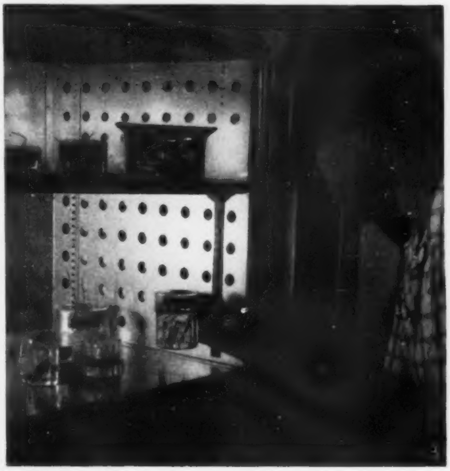

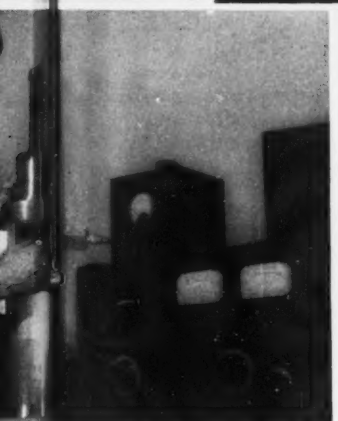

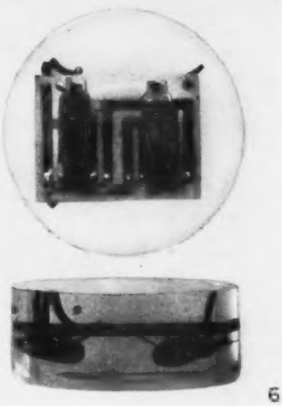

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le sui[illegible] mechanical and electrical insulation for electronic circuits that simple [illegible]ixing on a roll mill (1) produces a smooth dispersion that may tely. [illegible]ing in an oven (3) converts the resin to a solid. Two vitally dielectr[illegible]onstant, are measured at 100 megacycles (5). A plug-in multi-mplifie[illegible]rinted on ceramic plate (top and side views) (6) are among for pr[illegible]tion against shock, rough handling, and atmospheric conditions.

Compounds	Amount by weight
	%
2,5-Dichlorostyrene	33.0
Poly 2,5-dichlorostyrene	21.5
Styrene monomer	21.0
Polystyrene	11.0
Hydrogenated terphenyl	13.0
Solution containing 60% divinylbenzene	0.5

NBS casting resin formula

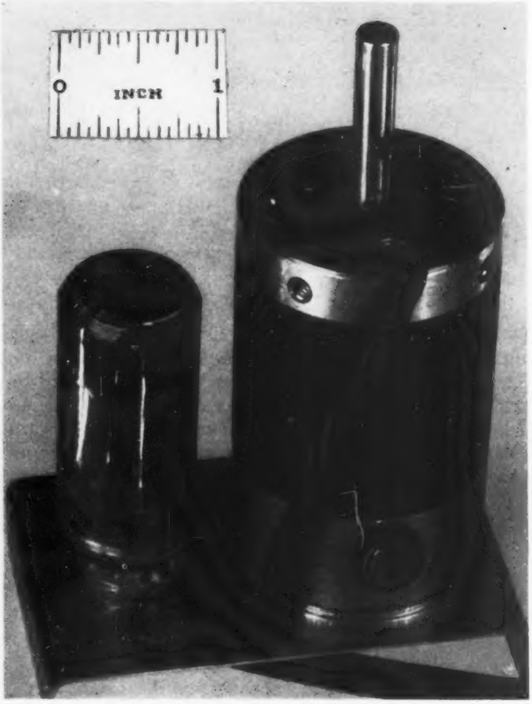
Electrical properties of the casting resin are affected only to a minor extent by the method of polymerization. Therefore the length of time for polymerization of the resin should be the minimum required for the chain length of the polymer to build up to a point beyond which there is no improvement in mechanical properties and all monomers are eliminated. The minimum time, however, varies with the catalyst, the percentage of catalyst used, and the temperatures at which the polymerization is initiated and carried out. In addition, the size of the casting must be considered.

As the polymerization reaction is exothermic and the resultant heat catalyzes the reaction, it is advisable to initiate polymerization at a low temperature and with a minimum amount of catalyst. Otherwise the reaction may become auto-catalytic with an increasing polymerization rate causing the final product to be cloudy, to contain many small bubbles, to be deficient in mechanical strength, and to give the appearance of being burned. For very large castings, a small amount of catalyst is used, and the casting is permitted to gel at room temperature thus preventing the auto-catalytic effect. As air has a slight inhibitory effect on the polymerization, the surface may be either covered with cellophane or flooded with glycerol after initial gelation has occurred, if a hard surface is desired.

As a result of investigation of many catalysts, it was found at the Bureau that benzoyl peroxide produced the best cured polymer. To improve the dissolving properties of the benzoyl peroxide and to eliminate the filler, the material was dissolved in acetone and then precipitated by water, filtered, and dried. This process produces extremely fine particles that quickly dissolve in the casting resin. Catalysts such as lauroyl peroxide, butyl hydroperoxide, caproyl peroxide, and caprylyl peroxide have been successfully used and may in a general way be substituted for benzoyl peroxide.

Applications and Significance

When employing the NBS Casting Resin in devices using glass vacuum tubes, proper protection for the tubes, such as rubber jackets, should be provided to prevent possible cracking by thermal and mechanical shock. All sharp corners should be eliminated from any object that is to be cast, as strains set up at these points may cause crazing. In order to eliminate or reduce these strains, and to obtain maximum hardness



Conventional subminiature components were potted to form the plug-in two-stage control amplifier (left) for register position control motor (right).

and total polymerization, it is advisable to continue the curing of the resin for a few days after the initial curing cycle.

When objects are to be suspended within the center of the casting resin, it is advisable first to gel a portion of the casting resin and then allow the gelled resin to support the sample. The mold is then filled completely with the casting resin and cured, after which the line of demarcation is invisible. Glass and properly lubricated metal molds have been used successfully. Silicone grease can serve as the lubricant.

The following are some of the measured mechanical and electrical properties of the NBS Casting Resin, cured at 50° C with 0.1 percent benzoyl peroxide:

Compressive strength, lb/in.[2]	17,100
Izod impact, ft lb/in. of notch	0.228
Coefficient of thermal expansion per ° C	11×10^{-5} (approx.)
Water absorption (24-hour immersion), %	0.01
Volumetric shrinkage on polymerization, %	8.0
Density of monomer	1.13
Heat distortion, ° C	68 to 70
Power factor (at 100 megacycles and 50% RH)	0.0004 to 0.0008
Dielectric constant (at 100 megacycles and 50% RH)	2.5
Dielectric strength ($^1/_{16}$-in. sample; volts/mil)	610 to 660
Volumetric resistivity, megohm-cm	10^{17}

The liquid resin may be stored at 0° C for a few months without a catalyst, and for a few weeks with a catalyst, before the viscosity increases to a point where pouring is difficult. At room temperature, the catalyzed casting resin gradually increases in viscosity and must be used in a day or two. The cured polymer may be drilled or turned on a lathe.

The special features of the NBS Casting Resin make feasible many new applications of electronic devices. By rigidly embedding electronic circuits or even complete plug-in subassemblies, the compound provides excellent electrical insulation as well as protection against rough handling and deteriorating atmospheric conditions. It is particularly well adapted for use with subminiature electronic equipment built by the printing technics now under developmental research by the Bureau and by industry. Several practical applications of resin-potted circuits at the Bureau have given operation comparable to that of conventionally constructed devices. The resin should be especially useful in high-impedance control devices in heavy industry to provide adequate protection against vibration, acid fumes, high humidity, salt spray, and other conditions that are encountered in steel mills, plating plants, and similar industries. Other potential uses include the potting of components and subassemblies for radar equipment, hearing aids, portable radio transmitters and receivers, and numerous subminiature electronic control devices.

Sodium Chlorite for Treatment of Raw Sugar

A new process for treating raw sugar with sodium chlorite, which inhibits fermentation while at the same time exerting slow bleaching action, has been developed at the Bureau. In the production of sugar there is considerable loss by bacterial action while it is in transit and storage, and the new process gives promise of effecting a substantial saving in the industry.

Several years ago, sodium chlorite appeared on the market as a new commercial chemical recommended for the bleaching of cellulose fibers. As little was known about reactions of the chlorites with carbohydrates, the subject was investigated at the Bureau with the object of providing a guide for its application as a bleaching agent.[2] It was found that sodium chlorite does not react with sugar over a period of many months, and that it has a desirable bleaching action on colored impurities. Under the conditions ordinarily employed in the refining industry, however, the use of sodium chlorite as a bleaching agent is not satisfactory because of the slowness of the bleaching action.

In the process developed at the Bureau and covered by a patent application (assigned to the Government and allowed March 6, 1947) the inertness of the reagent was turned to advantage. The raw sugar is sprayed or treated with a solution of sodium chlorite. The chlorite is allowed to remain with the sugar while it

is in transit and storage. During this period the reagent exerts a slow bleaching action and protects the sugar from bacterial action.

Curiously, sodium chlorite is much more effective in this process as an inhibitor of bacterial infection than chlorine or hypochlorite. Presumably the latter substances are rendered inactive by reaction with the sugar. The chlorite, however, being inert remains in the film surrounding the sugar crystals for a long time and inhibits bacterial action.

It is pointed out that the sodium chlorite solution can be applied with standard spraying equipment. Raw sugar must be centrifuged before it is packed to remove as much as possible of the molasses adhering to the sugar crystals, and the sodium chlorite can be applied at this point in the progress of the sugar from plantation to refinery. Care must be taken in the handling and storage of sodium chlorite and proper precautions exercised in its use because of its toxic effect if used under unsafe conditions.

[2] Allene Jeanes and H. S. Isbell, Chemical reactions of the chlorites with carbohydrates, J. Research NBS **27**, 125 (1941) RP1408; H. S. Isbell, Use of chlorites for treating raw sugars, J. Research NBS **27**, 491 (1941) RP1436.

Transition from Laminar to Turbulent Flow

A more complete understanding of the origin of turbulence near a surface along which air is flowing has resulted from wind tunnel experiments [3] at the National Bureau of Standards, with the cooperation of the National Advisory Committee for Aeronautics. The transition from smooth to turbulent flow—an important factor in the drag of modern aircraft—has been found to be directly related to the growth of velocity oscillations in the thin layer of air, known as the boundary layer, through which slipping takes place when relative motion of a solid surface with respect to air occurs.

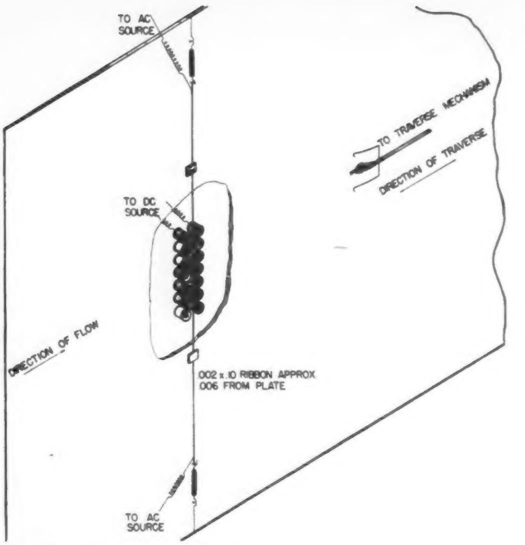
When a well streamlined body is subjected to air flow, the boundary layer envelopes it as a sort of skin. Friction between the body and air depends greatly upon the thickness of this layer and upon the ease with which the strata of air slide past each other. If this sliding is opposed only by the viscosity of the air, the flow is said to be smooth or laminar and friction is low. If, however, the flow becomes turbulent, the strata intermingle, no longer sliding easily over one another, and friction is high. For this reason new types of wings, known as laminar-flow airfoils, have been designed by the National Advisory Committee for Aeronautics in an effort to preserve laminar boundary-layer flow over as much of the wing surface as possible.

It is not an easy matter to maintain extensive laminar flow over a surface. As the length of surface over which the air has passed increases, the boundary layer thickens, becoming increasingly susceptible to disturbances. In other words, this layer apparently becomes less and less stable, and at some point transition to turbulent flow occurs. For many years one of the more important questions in this connection has been what determines the stability of a laminar boundary layer. Many investigations, both theoretical and experimental, failed to answer this question. However, in the early 1930's two German mathematicians, Tollmien and Schlichting, following a line of attack introduced by Lord Rayleigh in 1880, succeeded in finding criteria for stability of the boundary layer formed when air flows along a plane surface at constant mean speed. According to this theory, disturbances were assumed to cause variations in the velocity in the boundary layer and produce velocity waves of length determined by the frequency of the disturbance. Certain wavelengths would be amplified, while others would be damped. The growth of amplified waves was assumed to result in transition to turbulent flow.

This theory is not above criticism and was discredited from the start by experimentalists, because amplified waves could not be found. By use of the hot-wire anemometer, which was becoming an increasingly important tool for the investigation of such phenomena, it was shown that disturbances, such as those produced by turbulence in the surrounding flow, did cause irregular motions in the boundary layer, but there was no apparent growth of amplified waves leading to transition. The conclusion drawn from all experimental evidence was that the change to turbulent flow occurred when the boundary layer was sufficiently disturbed by external influences.

Such was the status of the problem when a fresh attack was made by the aerodynamics group of the National Bureau of Standards in 1940. As a result of this previous work, there was naturally considerable interest in the possible effect on a laminar-boundary layer if disturbances could be reduced to the vanishing point. One difficulty with wind-tunnel experiments up to that time had been the disturbing influence of stream turbulence, and the need for less turbulent wind tunnels was becoming increasingly urgent. Accordingly, the Bureau undertook an investigation of damping screens [4] and found that by their use turbulence could be reduced to previously unattainable levels. Along with this investigation, the extent of laminar flow along a flat plate was studied as the turbulence of the tunnel was reduced. Contrary to expectations, the extent of laminar flow did not continue to increase with reduction in stream turbulence, but reached a limit beyond which no further change occurred.

The hot-wire anemometer was then placed in the laminar boundary layer, to determine the extent to which the layer was disturbed when the external flow was known to be exceedingly smooth. A very strange phenomenon was now observed. The velocity was found to be varying in a sinusoidal manner with a frequency so definite that it could be determined with ease. The oscillation increased in amplitude with distance from the leading edge of the flat plate and finally broke into turbulent flow. Thus, amplified velocity waves



Velocity oscillations produced artificially in the boundary layer by forced vibration of the thin metal ribbon are picked up downstream by a hot-wire anemometer (upper right) and registered on an oscilloscope.

leading to transition were found to be a reality. Comparison with the Tollmien-Schlichting criteria showed that wave growth took place where it was expected according to theory.

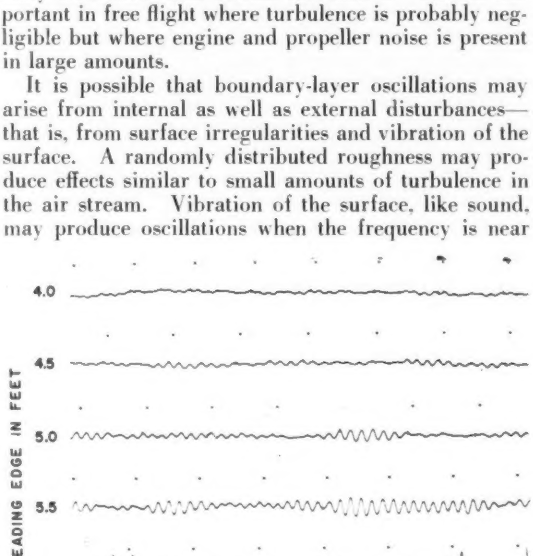
With this discovery, the stability theory, which had been mainly of mathematical interest, suddenly assumed real significance, and attention was immediately turned to further experimental studies designed to subject the theory to more rigorous tests. What was desired was the experimental counterpart of the mathematical procedure. In the theoretical analysis, a periodic stream function was substituted in a differential equation and solutions were obtained for certain prescribed conditions. The parallel experimental approach was then to cause a periodic disturbance in the boundary layer and to study the characteristics of the resulting wave.

To produce such boundary-layer disturbances, a metal ribbon was stretched across a flat aluminum plate at a known distance from the sharp leading edge of the plate and near enough to the surface to be within the boundary layer. The central portion of the ribbon was accurately spaced and held edgewise to the flow by thin spacing blocks. Electromagnets were placed on the back of the plate to produce a steady magnetic field, so that when an alternating current was passed through the ribbon it would vibrate in and out from the surface. When air was flowing, the waves produced by the vibrating ribbon traveled downstream past the hot-wire anemometer. The wire could be moved fore and aft along the plate at a fixed distance from the surface to examine the growth or decay of the wave as it traveled downstream through the boundary layer. Wavelengths were selected at will by choosing various frequencies for the ribbon. By this procedure, amplified, damped, and neutral waves were found, and wave diagrams were prepared similar to those indicated by the theory. From these diagrams were produced maps showing zones of damping and zones of amplification. On the whole the agreement with theory was excellent.

These investigations led to similar experiments using a curved surface, as well as a reexamination of the theory, at the California Institute of Technology. The ultimate result has been that the conditions governing stability of the laminar boundary layer are now understood, and the theory may be used with complete confidence.

Transition from laminar to turbulent flow may result from a velocity wave set up either by a vibrating object in the boundary layer, such as a vibrating ribbon, or by disturbances from the outside, such as stream turbulence and sound. Stream turbulence generally has a more nearly random distribution of energy with frequency than sound. Sound disturbances with a concentration of energy in frequency bands that are highly amplified by the boundary layer may thus be more conducive to early transition than stream turbulence. This is important in free flight where turbulence is probably negligible but where engine and propeller noise is present in large amounts.

It is possible that boundary-layer oscillations may arise from internal as well as external disturbances—that is, from surface irregularities and vibration of the surface. A randomly distributed roughness may produce effects similar to small amounts of turbulence in the air stream. Vibration of the surface, like sound, may produce oscillations when the frequency is near



Oscillograms show successive stages in the transition from laminar to turbulent flow. Experiments at the Bureau have shown that transition results from amplification of oscillations caused by variations of velocity within the boundary layer.

some value that is highly amplified by the boundary layer. An investigation of these and other phases of the problem may provide useful information on the important problem of transition from laminar to turbulent flow.

[3] Galen B. Schubauer and Harold K. Skramstad, Laminar boundary-layer oscillations and transition on a flat plate, J. Research NBS **38**, 251 (1947) RP1772.
[4] Damping wind-tunnel turbulence, NBS Technical News Bulletin **31**, 1 (1947).

Radio Propagation Conference

A Conference on Radio Propagation called by the Bureau's Central Radio Propagation Laboratory on May 8 to 10, was attended by about 75 specialists in the various phases of radio propagation. During the conference, sessions were held on the following topics: Ionospheric measurement technics and problems (J. H. Dellinger, chairman); ionospheric propagation analysis and prediction (Newbern Smith, chairman); physics of the ionosphere (M. A. Tuve, chairman); effects of the sun on the ionosphere (Donald H. Menzel, chairman); cosmic radio noise (K. G. Jansky, chairman); and propagation at VHF and higher frequencies (C. R. Burrows, chairman).

The status of work in these fields since the war was surveyed and ideas were interchanged on the most desirable lines that should be followed in the future. A number of government, university, and industrial laboratories are occupied in this work. The Conference was conducted by informal discussions and exchange of views, rather than by the presentation of formal papers.

The meeting was a successor to three types of meetings that had been held during the war. One was an annual conference on ionospheric knowledge held under the auspices of the Department of Terrestrial Magnetism, Carnegie Institution of Washington. The second was a series of semiannual conferences on tropospheric propagation held under the auspices of the National Defense Research Council. The third was a series of international conferences attended by the workers in propagation measurements held in Washington and in Ottawa.

The Joint URSI-IRE Meeting (International Scientific Radio Union, American Section, and the Institute of Radio Engineers), also held in Washington, D. C., during May, proved to be the largest such gathering in the history of these meetings, both as to the number of papers and attendance. The variety of subject matter and the scope of the ninety-odd papers presented at the sessions provided further evidence of the expanding horizon of the radio art in the postwar world. For the first time at these meetings, it was necessary to schedule simultaneous sessions. Of 600 registered at the meeting, approximately 150 came from outside the Washington area. The program included papers from Sweden and Canada, as well as the United States. Several members of the Bureau staff served on the committee for arrangements.

New NBS Hydrocarbon Samples

Seven new NBS standard samples of hydrocarbons just announced bring to 119 the total of these compounds now available for calibrating analytical instruments and apparatus in the research, development, and analytical laboratories of the petroleum, rubber, chemical, and allied industries. Since 1944, when the first of these NBS standard samples of hydrocarbons were made available, 100 additional compounds have been prepared through a cooperative undertaking between the Bureau and the American Petroleum Institute's Committee on Hydrocarbons for Spectrometer Calibration (Technical News Bulletin No. 350, June 1946).

The seven new compounds are as follows:

NBS sample number [a]	Compound	Amount of impurity [b]	Volume per sample [c] (liquid)	Price per sample
		Mole percent	*ml*	
253–58	2,2,4-Trimethylhexane	0.30 ± 0.20	5	$35.00
542–58	2,3,3-Trimethylhexane	.13 ± .06	5	35.00
255–58	2,3,5-Trimethylhexane	[d](.30 ± .20)	5	35.00
517–58	*n*-Butylcyclopentane	.034 ± .025	5	35.00
519–58	1-Hexene	.14 ± .08	5	35.00
527–58	*trans*-2-Hexene	.17 ± .11	5	35.00
538–58	2-Ethyl-1-butene	.10 ± .04	5	35.00

[a] The designation "–58" following the sample number indicates a sample of 5 ml sealed "in vacuum" in a special Pyrex glass ampoule with internal "break-off" tip.
[b] The purity has been evaluated from measurements of freezing points, as described in J. Research NBS **35**, 355 (1945) RP1676, unless otherwise indicated.
[c] Tolerance approximately ±10 percent.
[d] Estimated by analogy with isomers subjected to similar purification.

Instructions for transferring standard samples of hydrocarbons "in vacuum" are available on request. A complete list of NBS Standard Samples of Hydrocarbons, together with instructions for ordering, may also be obtained from the National Bureau of Standards, Washington 25, D. C.

NBS Scientists

Lauriston S. Taylor, Chief of the Bureau's X-ray Section, has been elected an Associate Fellow in the American College of Radiology. Associate Fellows are those deemed eligible, by the Board of Chancellors, because of noteworthy contributions and achievements in radiology, the science of radioactive substances and X-rays. Mr. Taylor has worked extensively on X-ray measurements, standardization, medical dosage requirements, and protection, and is a member of national and international organizations in this field.

Dr. P. J. Selgin, recently appointed to the staff of the Ordnance Development Division, has had varied experience in high-frequency radiation, electronics, and communications. A native of Milan, Italy, Dr. Selgin received his degree of doctor of engineering from the Royal Engineering School in that city. As head of a group of communications engineers, he directed devel-

opment of the Messina Straits Carrier in the Italian cable system. Dr. Selgin will work on phases of the electronic ordnance program for the military services.

Walter F. Stutz, chief of the Engineering Instruments and Mechanical Appliances Section, retired April 30 on completion of 35 years service with the Bureau. Mr. Stutz has done extensive work on fire-extinguishing equipment and materials, and was chairman of the Federal Specifications Board Committee for these items. Shortly after coming to the Bureau in 1912 he designed and supervised construction of a still-water flume for calibrating water-stream-current meters, equipment that is still in use and in which large numbers of such meters are tested annually. Mr. Stutz has also directed tests of pressure-measuring instruments, metering devices, stamp-vending machines, and similar equipment.

Robert C. Reichel has returned to the Bureau staff as research associate for the Waterproof Paper Manufacturers Association, which is cooperating with the Bureau in a comprehensive investigation of waterproofed papers. Mr. Reichel, a graduate of the University of Illinois, was formerly research associate at the Bureau for the Insulation Board Institute. More recently, he has been architectural field representative for the Portland Cement Association, following war service in the Navy's Civil Engineer Corps. Mr. Reichel will investigate such problems as accelerated aging tests, odor and taste in food packaging, and means of reducing flammability of the papers.

NBS Publications

Periodicals [5]

Journal of Research of the National Bureau of Standards, volume 38, number 6, June 1947 (RP1796 to RP1806, inclusive).

Title page, corrections, and contents for volume 37, Journal of Research, July to December 1946 (RP1723 to RP1757, inclusive). Price 5 cents.

Technical News Bulletin, volume 31, number 6, June 1947. 10 cents.

CRPL–D34. Basic Radio Propagation Predictions for September 1947. Three months in advance. Issued June 1947. 15 cents.

Nonperiodical

Research Papers [5, 6]

RP1787. Electrical methods for diamond-die production. Chauncey G. Peters, Walter B. Emerson, Karl Nefflen, Forest K. Harris, and Irvin L. Cooter. Price 10 cents.

RP1788. Effect of artificial aging on the tensile properties and resistance to corrosion of the 24S–T aluminum alloy. Hugh L. Logan and Harold Hessing. Price 15 cents.

RP1789. Cooperative analysis of a standard sample of natural gas with the mass spectrometer. Martin Shepherd. Price 10 cents.

RP1790. Infrared emission of spectra of krypton and argon. Curtis J. Humphreys and Earle K. Plyler. Price 10 cents.

RP1791. Dipole moments and resonance of some benzein indicators and related compounds. Arthur A. Maryott and Soloman F. Acree. Price 10 cents.

RP1792. An improved Geiger-counter arrangement for determination of radium content. Francis J. Davis. Price 10 cents.

RP1793. Changes caused in the refractivity and density of glass by annealing. Arthur O. Tool, Leroy W. Tilton, and James B. Saunders. Price 10 cents.

RP1794. Conductimetric titrations of acids and bases in benzene and dioxane. Arthur A. Maryott. Price 10 cents.

RP1795. Analysis of alkylates and hydrocodimers. Augustus R. Glasgow, Jr., Anton J. Streiff, Charles B. Willingham, and Frederick D. Rossini. Price 25 cents.

Simplified Practice Recommendations [5]

R225–47. Asphalt tile. 5 cents.

Miscellaneous [5]

M183. Temperature interconversion tables (°C—°F) and melting points of the chemical elements. 5 cents.

M185. Rubber research and technology at the National Bureau of Standards. 10 cents.

Letter Circulars [7]

LC857. Terminology and symbols for use in ultraviolet, visible, and infrared absorptometry.

LC858. Publications relating to building codes and construction practice—home building—building material specifications—home maintenance. (Supersedes LC843).

LC859. Paint, varnish, lacquer, and related products—list of National Bureau of Standards publications and Federal Specifications. (Supersedes LC795).

Articles by Bureau Staff Members in Outside Publications [8]

The Bingham viscometer and viscosity standards. James F. Swindells. Journal of Colloid Science (125 East Twenty-third Street, New York 10, N. Y.) **2,** No. 1, 177 (February 1947).

Distribution of bond stress in concrete pull-out specimens. David Watstein. Journal of the American Concrete Institute (7400 Second Boulevard, Detroit 2, Mich.) **18,** No. 9, 1041 (May 1947).

Index to the literature on spectrochemical analysis, part II, 1940–1945. B. F. Scribner and W. F. Meggers. American Society for Testing Materials (1916 Race Street, Philadelphia 3, Pa.). 180 pages (1947).

A vacuum tube for acceleration measurement. Walter Ramberg. Electrical Engineering (330 West Forty-second Street, New York 17, N. Y.) **66,** No. 6, 555 (June 1947).

Measurement—tool of science and industry. Hugh L. Dryden. Instruments (1117 Wolfendale Street, Pittsburgh 12, Pa.) **20,** No. 5, 435 (May 1947).

The use of damping screens for the reduction of wind-tunnel turbulence. Hugh L. Dryden and Galen B. Schubauer. Journal of the Aeronautical Sciences (2 East Sixty-fourth Street, New York 21, N. Y.) **14,** No. 4, 221 (April 1947).

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[5] Send orders for publications under this heading only to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Annual subscription rates: Journal of Research, $1.50 (foreign, $5.50); Technical News Bulletin, $1.00 (foreign, $1.35); Basic Radio Propagation Predictions, $1.50 (foreign, $2.00). Single copy prices of other publications are indicated in the lists.

[6] Reprints from May Journal of Research.

[7] Available on request from the National Bureau of Standards, Washington 25, D. C. Letter Circulars are prepared to answer specific inquiries addressed to the Bureau, and are sent only on request to persons having a definite need for the information. The Bureau cannot undertake to supply lists or complete sets of Letter Circulars or send copies automatically as issued.

[8] These publications are not available from the Government. Requests should be sent direct to the publishers.

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